Ice storm damage: Effects of competition and fertilization on the growth of sugar maple trees

by R.A. Lautenschlager[1], John H. Pedlar[2], John A. Winters[3] and Cathy M. Nielsen[4]

Treatment plots in blocks established in productive sugar maple (*Acer saccharum*) bushes throughout southeastern Ontario were used to quantify effects of fertilizers, vegetation control and interactions on maple growth following the 1998 ice storm. Treatments were applied during the spring of 1999. Increment cores from six mature sugar maple trees in each plot in each block were extracted and examined during October 2001. Maple growth was highly variable before the storm, but fell to a 30-year low during both the first and second year after the storm. Growth reductions increased with increasing crown damage. Treatment-related statistical differences were marginal; however, the data suggest that phosphorus and potassium additions and competition control improved the growth of ice-damaged mature sugar maple trees. The combination of competition control and fertilization increased growth of ice-damaged maple the most.

Key Words: *Acer saccharum*, increment cores, glyphosate, phosphorus, potassium

Les parcelles traitées dans les blocs mis en place dans les érablières à sucre (*Acer saccharum*) productive dans toute la région du sud-est de l'Ontario ont été utilisées pour quantifier les effets des fertilisants, du contrôle de la végétation et des interactions sur la croissance des érables suite à la tempête de verglas de 1998. Les traitements ont été réalisés au printemps de 1999. Des carottes d'accroissement de six érables matures de chacune des parcelles-échantillons ont été prélevées et examinées au cours du mois d'octobre 2001. La croissance des érables était grandement variable avant la tempête, mais est tombé à un niveau jamais enregistré en trente ans au cours de la première et seconde année après la tempête. La réduction de la croissance augmentait en fonction de l'accroissement des dégâts de cime. Les différences statistiques reliées aux traitements étaient marginales, les données suggérant que l'apport de phosphore et de potassium ainsi que le contrôle de la compétition ont amélioré la croissance des érables à sucre matures endommagés par le verglas. La combinaison du contrôle de la végétation et de la fertilisation a permis d'enregistrer le meilleur accroissement de la croissance des érables à sucre.

Mots-clés: *Acer saccharum*, carottes d'accroissement, glyphosate, phosphore, potassium

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Introduction

Ice storms and resulting damage are naturally recurring disturbances in a variety of northern ecosystems (Abell 1934, Irland 1998). In North America, ice storm probability is high in areas where freezing rain is frequent. From January 5 to 10, 1998, a combination of meteorological events occurred over the St. Lawrence and Ottawa River valleys and spread east through upstate New York into parts of New England and into the Canadian Maritimes. These conditions produced extended periods of super-cooled rain across the area, which froze on contact, producing extensive damage to trees and forests (Lautenschlager and Nielsen 1999). The 1998 storm was unique because of the broad geographical area affected and the amount of freezing rain deposited, roughly twice the maximum previously recorded in these areas, making this one of the most destructive single disturbances recorded in North America.

As has been reported previously (Carvell *et al.* 1957), susceptibility to the 1998 ice storm varied considerably among tree species; hardwoods being more susceptible than conifers (Irland 1998). Interest has historically focused on assessment

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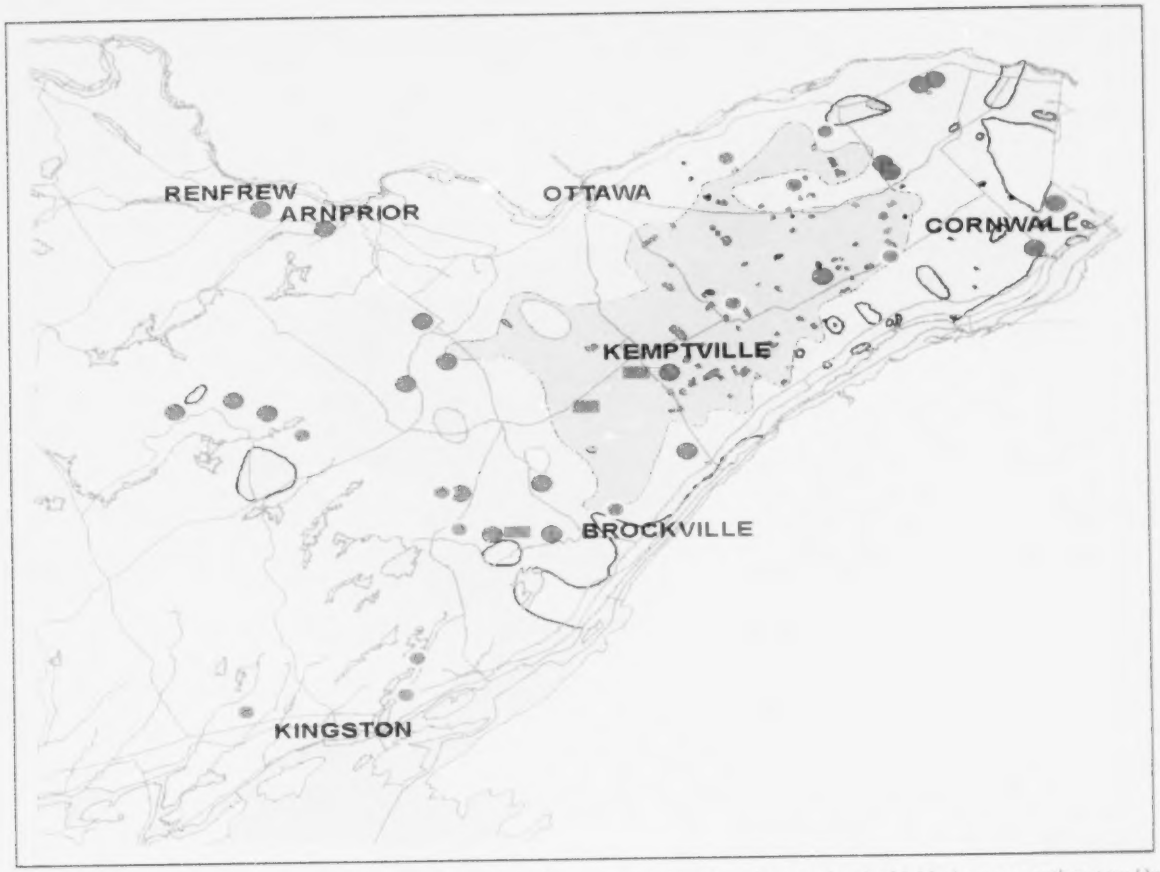


Fig. 1. Map of study area, showing block locations [small ovals (main experiment) and rectangles (herbicide)] across southeastern Ontario. Spatial extent and severity of ice damage in eastern Ontario is also shown; damage severity increases with increasing darkness of shading.

of damage to tree crowns with little longer-term work documenting post-damage recovery. Although damage to sugar maples (*Acer saccharum*) from the 1998 ice storm was intermediate in severity (Hopkin *et al.* 1999, Manion *et al.* 2001), a few stands managed by maple syrup producers in southeastern Ontario suffered, on average, as much as 77% crown damage (Lautenschlager and Winters 2001). Because it was unclear what, if any, treatment might help these damaged stands recover, extensive discussions were held with experts in sugar maple ecology, health, and production. Two approaches, fertilizers and understory vegetation control emerged, as potential remedial treatments, from those discussions. Most experts agreed that one or both might enable damaged trees to resume sap (volume and sweetness) production sooner or save severely damaged trees from dying. However, sugar maple producers opposed herbicide use in their managed maple stands.

Input from experts provided the foundation for developing a post-storm interdisciplinary experiment in managed sugar maple stands across southeastern Ontario. The experiment focused primarily on responses by sugar maple trees, but also documented responses of other major biotic components to ice damage and fertilizer applications. In addition, there was a sub-experiment focusing on understory vegetation control and interactions between vegetation control and the complete fertilizer treatment (Lautenschlager and Nielsen 1999).

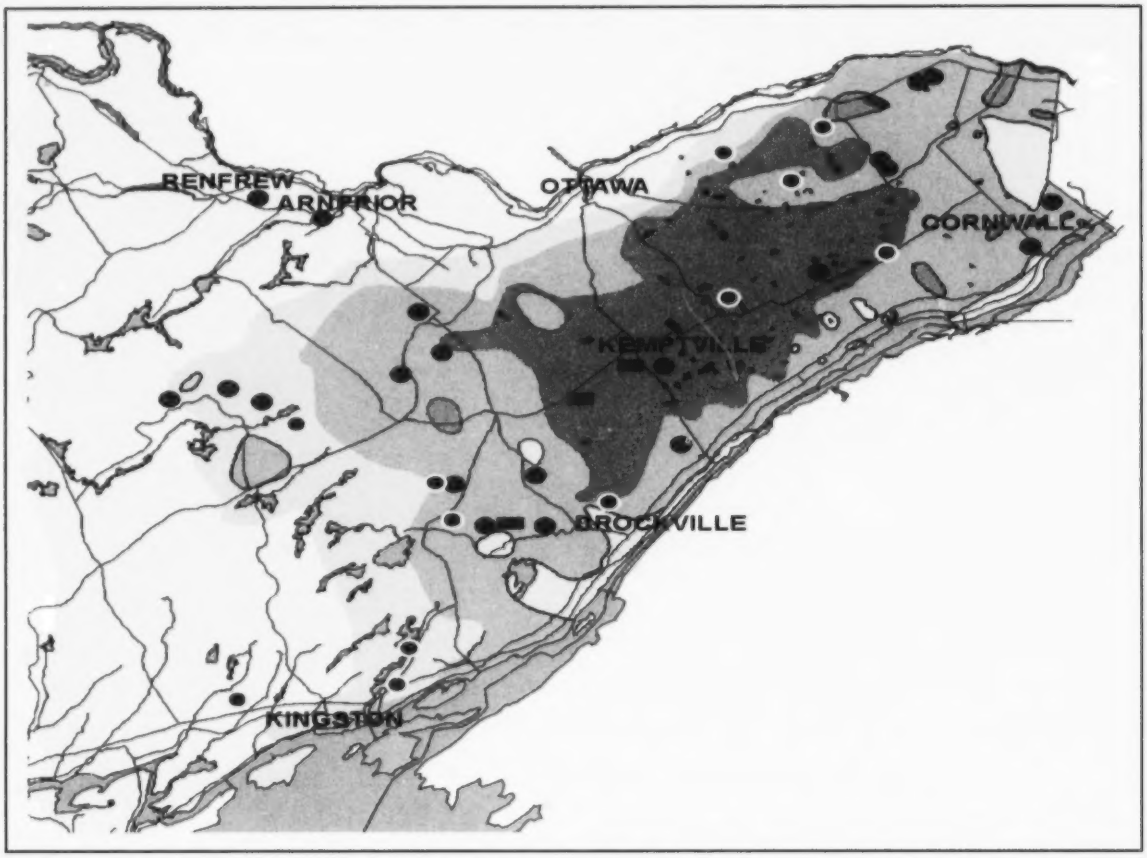
The objective of this paper is to document effects of ice damage and post-damage remedial treatments on post-damage mature maple growth in managed sugarbushes in southeastern Ontario.

Study Area

The study area was located within the Great Lakes-St. Lawrence Forest Region (Rowe 1972), and covers much of southeastern Ontario. It was bounded by Quebec to the north and east, the St. Lawrence River to the south, and a line roughly between Arnprior and Kingston to the west (Fig. 1). Lautenschlager and Nielsen (1999) provided study area details. Briefly, the area has: a generally flat to gently rolling topography averaging 123 m above sea level; extremely heterogeneous soils; a mean July daily temperature maximum of 27 °C; a mean January daily temperature minimum of –15 °C; and annual precipitation averaging 852 mm, with 203 mm as snow.

Methods

Thirty-eight 1-ha blocks [33 damage- and fertilizer-focused, two damage-focused only, three damage-, herbicide- and fertilizer-focused] each with four plots/block (Fig. 2) were established in previously thinned (sometimes repeatedly), productive, mature, sugar maple bushes across southeastern Ontario (Fig. 1). Six focus sugar maple trees/plot (24/block), chosen



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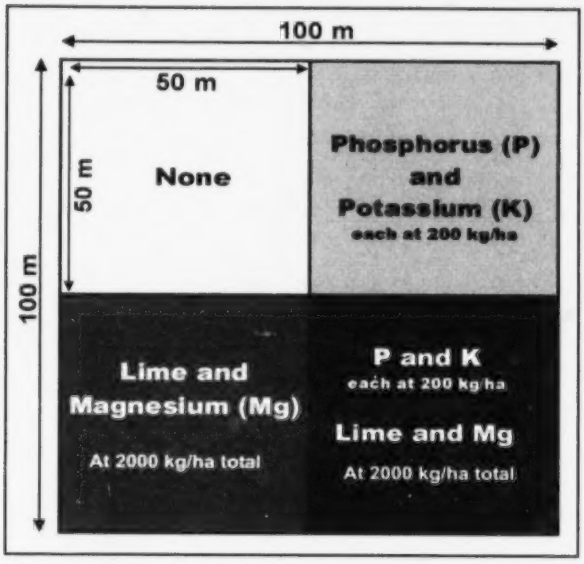

Fig. 2. Overview of the fertilizer treatment applications used at each study block.

to represent the damage sustained across that block, were located centrally in plots when blocks and plots were established in 1998. Focus trees were measured (dbh, height, crown damage %) during the fall of 1998.

Fertilizer treatments, applied to plots in June 1999, consisted of: none; dolomitic [containing magnesium (Mg) – 55.5% $CaCO_3$, 42.5% $MgCO_3$] lime @ 2000kg/ha; phosphorus (P) and potassium (K) each at 200kg/ha; and P and K (each at 200kg/ha) and dolomitic lime. Details related to P and K formulations, and amounts delivered are provided in Table 1. Initial applications were via mechanical spreaders but these were inadequate. Therefore, the bulk of the applications were from scoops repeatedly dipped into buckets of fertilizers and broadcast as applicators walked between string lines established to ensure a thorough distribution across treatment plots.

Vegetation control was applied to sugar bushes that received 40% to 60% crown damage. Two of the three vegetation control blocks had previously been used for maple sugar production but were inactive when the experiment was implemented. The third block was a younger sugar maple stand that had never been used for maple sugar production. Applications were made to the three 1-ha blocks; which were divided into four plots. Treatments consisted of: none; Vision® herbicide (3% solution 10.8L/ha); fertilizer – dolomitic lime @ 2000kg/ha plus P and K, each at 200kg/ha; and herbicide plus fertilizer. Herbicide treatments were applied with a backpack mist-blower on June 11 and 12, 1999.

Growth, responses to damage and remedial treatments were based on an analysis of growth seen in increment cores collected at breast height (1.3 m above ground) in October 2001. Three cores were taken from all focus trees. Most trees grew on relatively flat terrain and cores from those individual trees were taken from opposite sides (180°), generally north and south, and from one additional point at breast height. On sloped terrain, cores were taken from trees perpendicular to the slope and from one additional point, all at breast height.

Extracted cores were stored on ice in a cooler as they were collected and then transferred to a freezer at the end of each collection day. Frozen cores were thawed and stained with a potassium iodide solution (0.25 gm KI, 0.10 gm Iodine, 25 ml H_2O) before they were examined. Cores were examined with a Tree Ring Increment Measuring (TRIM) system (Fayle and MacIver 1986) that included a binocular microscope and measuring platform hard-wired to a personal computer for recording. Ring widths were measured under magnification to the nearest 0.001 mm. If the first two cores examined were readable, the third sample was stored and not examined. The third sample was examined only if problems developed when attempting to read the first or second core. Ring widths were cross-dated, 1972 through 2002, using major growth troughs and peaks. The trough following the 1998 ice storm was a key year for cross-dating. Even so, there was unexplainable asynchronous variability within and among sampled trees.

Statistical Analyses

Measurements from the two cores/tree were averaged and annual growth converted to annual basal area increment (BAI) using the method outlined by Kolb and McCormick (1993), who note that conversion of ring widths to BAIs helps remove variation in radial growth attributable to increasing circumference. Since study blocks were established at locations that varied widely with respect to maple productivity, post-ice storm growth was expressed as a proportion of pre-ice storm growth. This was accomplished by dividing the BAI for a particular tree in a given post-storm year by the average BAI of that tree during the 10 years prior to the ice storm. We examined several time frames (i.e., 2, 4, 5, 10, and 30 years) for standardizing post-storm growth rates. Results from most were similar, but the 10-year average produced the strongest statistically significant relationships.

Two experiments were analyzed: 1) the ice damage/fertilizer experiment (35 total blocks), and 2) herbicide/fertilizer experiment (three blocks). Given the low sample size associated with the herbicide/fertilizer experiment, we consider those findings

Table 1. Amount of phosphorus and potassium (elemental and product) applied to fertilizer treatment plots in a study examining the effect of ice storm damage and post-damage remedial measures in sugar maple stands in eastern Ontario

Element	Target Rate (element/ha)	Formulation	% of element in formulation[a]	% formulation in product	% element in product	Multiplication factor[b]	kg/ha of product required
P	200 kg/ha	P_2O_5	43.7	46	20	5	1000
K	200 kg/ha	K_2O	82.9	50	41.45	2.5	500

[a]Calculation of % element in the formulation:
Atomic weight of elements: P = 31; K = 39; O = 16.
P_2O_5: 2*31/(2*31 + 5*16)= 0.437 (proportion of P in P_2O_5).
K_2O: 2*39/(2*39 + 16) = 0.829 (proportion of K in K_2O).
[b]Target rate of element (kg/ha) * Multiplication factor = Amount of product to be applied (kg/ha).

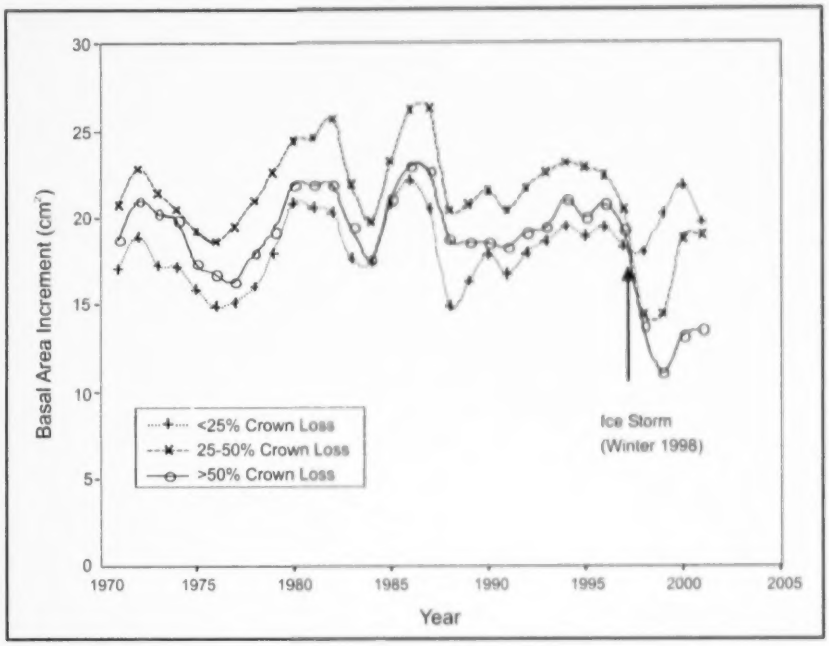

Fig. 3. Annual variation in maple tree growth (BAI; cm^2) between 1971 and 2001 based on increment cores taken from trees in southeastern Ontario with varying levels of ice damage.

exploratory and present them as means and standard errors. The fertilizer was applied in a randomized block design, thus lending itself to an analysis that uses the BLOCK variable to remove extraneous variation among sites. However, we were also interested in potential interactions among fertilizer treatments, ice damage, pH, and dbh (both reported by Lautenschlager and Winters 2001), which are confounded with BLOCK and therefore cannot be examined with BLOCK in the same analysis. We ran a preliminary analysis that examined interactions of interest (without including BLOCK), and found none of them to be significant. Therefore, pH and dbh were dropped and BLOCK was included in the final analysis to remove site-to-site variation that might otherwise mask fertilizer effects. The damage/fertilizer experiment was analyzed in two repeated measures ANOVAs, both with sub-sampling (SAS Institute Inc. 1996). The first ANOVA presented shows the effects of ice damage, time (YEAR), and BLOCK in each of the four growing seasons following the ice storm (i.e., 1998–2001). Since fertilizer treatments were not applied until the second growing season after the ice storm, we present a second ANOVA focused on the effect of fertilizer treatments on tree growth in the three growing seasons following treatment (i.e., 1999–2001).

In both of the ANOVAs presented, trees were considered nested sub-samples within treatment plots and each year was considered a repeated measure on a treatment plot. Analyses were first run with all interaction terms, but non-significant interactions were removed from the final model. Appropriate error terms for significance testing were identified by calculating expected mean squares. Terms with $P < 0.10$ in the final model are discussed.

Results

Long-term Yearly Variation in Maple Growth

There was considerable year-to-year variation in maple growth between 1971 and 2001 (Fig. 3). In the 27 years preceding the ice storm there was no long-term trend in BAI (regression equation: BAI = 0.0491 × YEAR - 77.604; $R^2 = 0.0437$; $F_{1,25} = 1.16$; $P > 0.10$), suggesting that the maple stands studied maintained a relatively constant level of growth prior to the ice storm. In 1998—the first growing season following the ice storm—growth rates of trees with moderate (25–50% crown loss) and severe (>50% crown loss) damage were the lowest encountered in any of the previous 27 years. The 1999 growing season was worse still for severely damaged trees and only slight improvement was observed in the 2000 and 2001 growing seasons (Fig. 4). Growth of moderately damaged trees stabilized in 1999 and improved considerably in 2000 and 2001; when their growth nearly attained pre-ice storm levels (Fig. 3). Prior to the ice storm, trees that were lightly damaged (0–25% crown loss) by the storm showed consistently lower growth rates than trees that received heavier storm damage (Fig. 3). However, lightly damaged trees maintained higher growth rates in all four post-ice storm years. For lightly damaged trees, growth in 1998, 1999, and 2001 was about average, while growth in 2000, which received more rain during the growing season than any other year during the study, was above average.

Factors Affecting Post-Ice Storm Maple Growth

Results from a repeated-measures analysis relating growth in the four years following the ice storm to ice damage and time (YEAR) are shown in Table 2. Of the factors examined, ice damage had the greatest effect on tree growth. Growth index declined linearly with increasing damage, such that 80% canopy loss resulted in an annual growth reduction of about 50% (Fig. 5). Note that each data point in Fig. 5 represents the mean growth and ice damage level on each plot (i.e., summarized at experimental unit level). For this reason, the R^2 value in Fig. 5 is different than that reported in Table 2 because the ANOVA took tree-to-tree (i.e., sub-sample) variation into account. Growth also varied ($P < 0.0001$) among post-ice storm years (Table 2, Fig. 3). An a posteriori means test indicated that growth

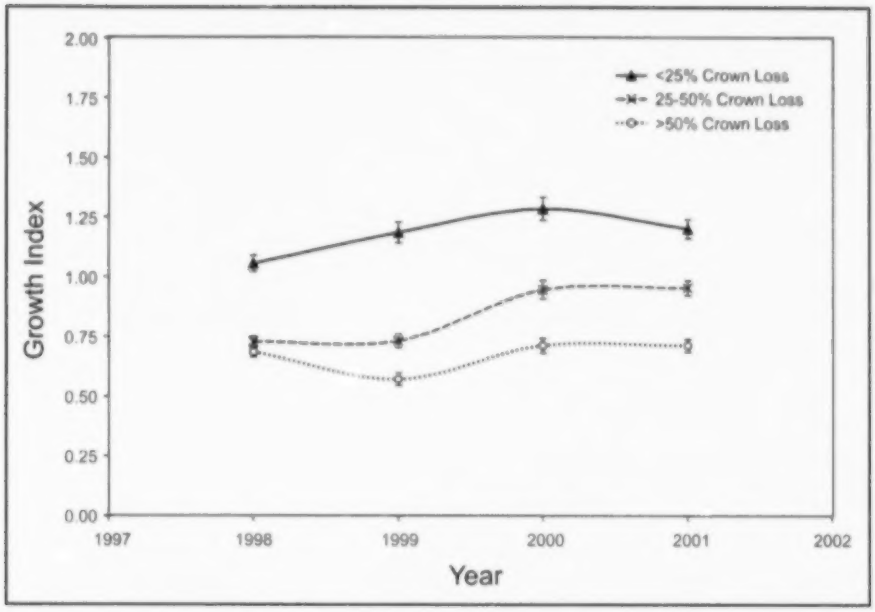

Fig. 4. Interaction plot showing year-to-year variation in maple growth (mean ± S.E.) for three ice damage classes. The growth index is basal area increment expressed as a proportion of average basal area increment in the 10 years prior to the ice storm (see text for details).

Table 2. Summary of repeated-measures ANOVA relating post-ice storm maple tree growth to ice damage

Source	df	Sums of Squares	Mean Squares	F	P	Partial R^2
DAMAGE	1	40.43	40.43	133.33	<0.0001	0.39
YEAR	3	4.85	1.62	38.51	<0.0001	0.05
DAMAGE*YEAR	3	1.70	0.57	13.51	<0.0001	0.02
PLOT(BLOCK)[a]	133	40.33	0.30			
PLOT*YEAR(BLOCK)[b]	399	16.75	0.04			

[a]Mean square used as denominator for testing all main effects and interactions not involving the term YEAR.
[b]Mean square used as denominator for testing all main effects and interactions involving the term YEAR.

rates in 1998 (0.87 ± 0.28; mean ± s.d.) and 1999 (0.90 ± 0.38) were significantly lower than those in 2000 (1.07 ± 0.43) and 2001 (1.03 ± 0.34). Diameter at breast height was marginally significant ($P = 0.068$), showing a weak, negative correlation with maple growth.

There was a significant DAMAGE × YEAR interaction (Table 2). Growth of lightly damaged trees (0–25% crown loss) tended to peak in 2000, with moderate growth in 1999 and 2001; moderately damaged trees (25–50% crown loss) showed signs of recovery (i.e., improved growth) in 2000 and 2001; and heavily damaged trees (>50% damage) showed little sign of recovery in any of the four post-ice storm years (Fig. 4).

Results from the repeated-measures analysis, relating growth to fertilizer treatments in the three years following application, are shown in Table 3. We reiterate that since preliminary analyses showed no significant interactions between TREATMENT and either DAMAGE, dbh or pH, we used BLOCKS to remove extraneous variation among sites. Fertilizer treatments had a significant ($P = 0.048$) effect on post-ice storm tree growth, but explained only a small amount of the total variance (Table 3). An a posteriori means test did not distinguish among fertilizer treatment means (±s.d.): none (0.96 ± 0.34), lime + P&K (1.04 ± 0.38), P&K only (1.07 ± 0.39), and lime only (0.93 ± 0.30). There was a marginally significant interaction between TREATMENT and YEAR suggesting that the effect of fertilizer varied slightly among years (Fig. 6). In

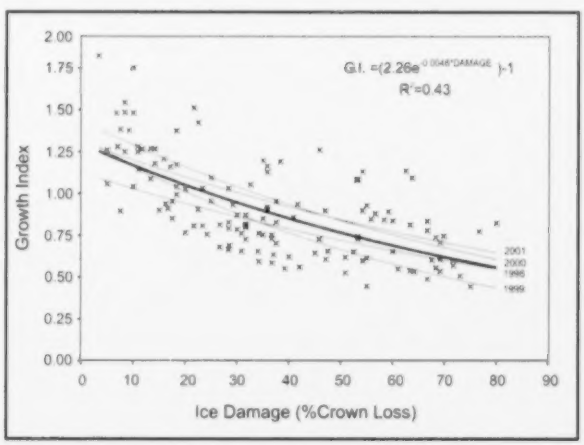

Fig. 5. Relationship between maple growth and ice damage. The light lines show the best-fit line for each of four years following the 1998 ice storm. The dark line is the overall best fit, based on the data points shown in the figure (i.e., mean growth index on each treatment plot).

1999, the year that fertilizer treatments were applied, growth was similar on all treatment plots; by 2000, plots treated with P&K only, and lime + P&K showed evidence of increased growth as compared to control (none) and lime only plots. This effect

Table 3. Summary of repeated-measures ANOVA relating post-ice storm maple tree growth to fertilizer treatments

Source	df	Sums of Squares	Mean Squares	F	P	Partial R^2
BLOCK	34	47.37	1.39	7.83	<0.0001	0.60
TREATMENT	3	1.54	0.51	2.89	0.0392	0.02
YEAR	2	3.38	1.69	48.78	<0.0001	0.04
TREATMENT*YEAR	6	0.42	0.07	2.03	0.0622	0.01
PLOT(BLOCK)[a]	96	17.07	0.18			
PLOT*YEAR(BLOCK)[b]	260	9.02	0.03			

[a]Mean square used as denominator for testing all main effects and interactions not involving the term YEAR.
[b]Mean square used as denominator for testing all main effects and interactions involving the term YEAR.

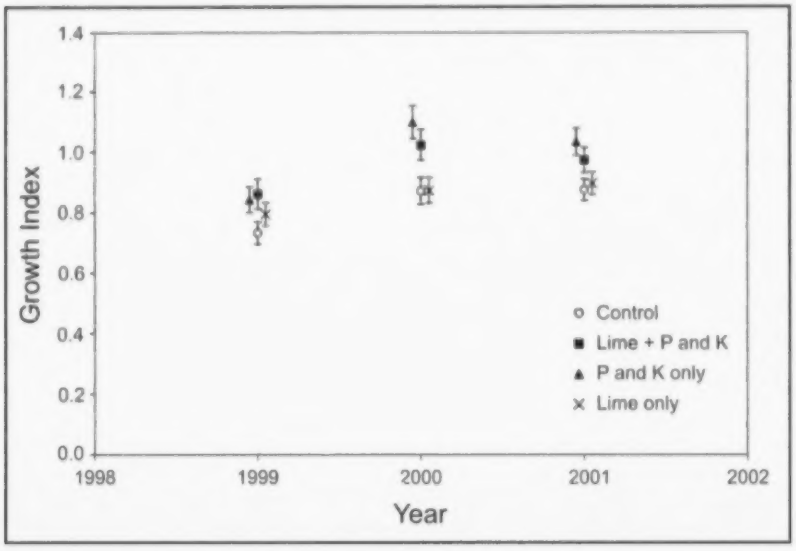

Fig. 6. Interaction plot showing how the effect of fertilizer on maple tree growth (mean ± S.E.) varies among years. Growth is basal area increment expressed as a proportion of average basal area increment in the 10 years prior to the ice storm (see text for details).

was reduced in 2001, possibly due to the poorer growing conditions brought about by a drought in that year.

Herbicide Effects on Maple Growth

Herbicide treatments were examined on three blocks, all with moderate damage. By chance, growth on treatment plots was lower than that on untreated plots one year before treatment, in 1998 (Table 4). Therefore, although actual growth responses are reported (Table 4), we discuss the results in terms of percent change in relation to the 1998 pre-treatment levels. Plots receiving the combined herbicide and fertilizer treatment showed a rapid growth response; achieving growth levels in 1999 that were nearly 100% greater than those in 1998 and 20% greater than the pre-ice storm average. This response was unparalleled on the other treatment plots, where the largest increases (~10%) occurred on the untreated and herbicide-treated plots. The year 2000 was a good-growing season on all plots, but the combination of fertilizer and herbicide treatments continued to outperform the other treatments with nearly a 200% increase over pre-treatment growth levels in comparison to 55%, 47%, and 44% increases on herbicide, untreated, and fertilizer plots, respectively. A similar pattern was again apparent in 2001, although growth declined on all plots, probably due to a region-wide drought in that year.

Discussion

Although fertilizers were applied during the spring of 1999, the 1999 growing season was dry and therefore there was limited potential for the fertilizers applied to become available to plants on treated sites before the 2000 growing season. Snow melt during the spring of 2000 combined with abundant precipitation that year, should have made much of the applied fertilizer available to maple trees and other plants growing on treated blocks.

The herbicide treatment controlled much of the near-ground vegetation, up to 3.0 m. Other studies on these blocks found that herbicide treatments had very little effect on soil characteristics, litter accumulation, root mass, and carbon cycling by the microbial biomass, or near-ground microclimate (soil moisture, temperature, humidity, etc.) in treated plots.

Sugar maple BAI before the ice storm was highly variable, likely because of differences in sites, management history, climate, and periodic insect outbreak levels. The ice storm, however, forced damaged trees to a 30-year low, and unlike previous low growth years the 1998 ice storm caused average BAI of moderately and severely damaged trees to remain low for several years. Still, sugar maple growth for all damage classes had either recovered or started to recover by 2000. This suggests that crown damage may simply be one more environmental variable that sugar maple, known to be stress-tolerant, has evolved to tolerate. Although damaged trees—even those that were severely damaged may recover—projections of recovery (based on Fig. 3) for severely damaged trees (=50% crown damage), suggest that this group will take eight years to grow at a rate similar to their growth before the storm. Similar projections suggest that trees that suffered intermediate damage (25–50%), will recover in about half that time.

Table 4. Mean growth (± S.E.) on herbicide plots in each post-ice storm year. The growth measure is basal area increment expressed as a proportion of average basal area increment in the 10 years prior to the ice storm (see text for details)

		1998	1999	2000	2001
Treatment	N[a]	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.
None	17	0.89 ± 0.10	0.98 ± 0.17	1.31 ± 0.30	1.22 ± 0.30
Herb. + Fert.	17	0.64 ± 0.06	1.20 ± 0.35	1.83 ± 0.48	1.46 ± 0.30
Fert. Only	18	0.72 ± 0.06	0.74 ± 0.07	1.04 ± 0.10	0.91 ± 0.08
Herb. Only	16	0.78 ± 0.11	0.87 ± 0.15	1.21 ± 0.25	1.12 ± 0.16

[a]Number of trees receiving treatment; varies between treatments due to missing growth data for some trees.

Fertilizers and competition control, with glyphosate herbicide, were applied with the hope that one, or both might aid recovery of damaged sugar maples or decrease the probability that damaged trees would die. Although results suggests that P and K may have improved maple growth following their application in 1999, adding dolomitic lime at two tons/ha has yet to improve post-damage maple growth. Although not statistically significant, growth responses to competition control suggest that moderately to severely damaged trees grew better when both understory competition was controlled and lime and P&K were added. Although many believe that the growth of mature sugar maple trees is not affected by competition, the responses by moderately to severely damaged sugar maple trees in this study suggests that near-ground competition may limit the ability of these trees to take advantage of added nutrition. Additional work documenting responses to these treatments for a range of ages, damage levels, or other variables could be of value to anyone managing mature sugar maple in the future.

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